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Design of Energy Harvesting Circuit for Low Power Application

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Abstract **- Piezoelectric energy harvesting is the technology to convert wasted vibration energy to an electrical energy output. A considerable amount of energy is dissipated in PEH to flip the output voltage through the internal capacitor and resistor of piezoelectric (PZT) material. One of the most effective techniques to harvest this power loss is called Synchronized Switch Harvesting on Inductor (SSHI) technique. Parallel SSHI technique has been used to flip the terminal voltage of the PEH through external inductor. A new simple and effective self-powered circuit has been introduced in this paper for this purpose. The new circuit uses two capacitors only to detect the flipping points of terminal voltage and enhance the power output.**

Keywords: **Self powered, SSHI, Piezoelectric, PHE.**

I. INTRODUCTION

The output power from piezoelectric energy harvester (PEH) is an AC with amplitude and frequency that depend on the mechanical stress on piezoelectric (PZT) materials and the electric circuit connected to it. The equivalent circuit of the PEH is a current source in shunt with resistor and capacitor as shown in Fig.1 [1]. The generated power from the PEH is very small to be used to feed loads directly. It is also not suitable to be used in most applications without battery or super-capacitor to accumulate the generated power to be used when required. For this reason, a r ectifier should be used to convert ac to dc power. The literatures recommend using a diode bridge rectifier rather than half-wave diode rectifier [1]. Also, voltage multiplier can be used to extend the operating range and to increase the dc output power extracted from the PEH [2], [3]. The dc output power from the rectifier may be used to charge a battery or to feed load directly, known as Standard SPEH [4]. The SPEH is characterized by high output voltage and low current which is not suitable for small battery with low rated voltage. So, operating the SPEH in a low terminal voltage will considerably reduce the extracted power and efficiency. Therefore, a device that can interface a battery having low voltage with high terminal voltage from the PEH is required.

II. LITERATURE REVIEW

Piezoelectric materials are perfectly used for energy harvesting from ambient vibration sources, because they can efficiently convert mechanical strain to an electrical charge without any additional power and have a simple mechanical structure [5]. They also have many advantages over other alternative techniques such as: large power density, ease of applications, and capability to be fabricated at different scales: macro, micro, and nano-scale.

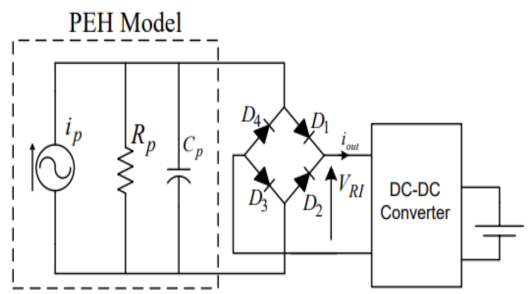

Fig. 1 Simple piezoelectric harvesting circuit

Sodano *et al.* developed a model of the piezoelectric energy harvesting device and estimated the electric charge output for piezoelectric energy harvesting. In 2004, they reviewed piezoelectric power harvesting from vibration and discussed the future goals that must be achieved such as improving power output and energy conversion efficiency. They compared different cantilever piezoelectric energy harvesting devices, including MIDE Quick Pack, PZT-5A, PZT-5H, and MFC. The output power from either Quick Pack or MFC harvester was lower than extracted from PZT. PZT material was more effective to recharge capacitive loads. The low power outputs of Quick Pack and MFC resulted from their low capacitance characteristics [6].

Ottman and *et. al.* [7] and [8] introduced the first dc-dc buck converter to interface the low voltage battery with high voltage from the PEH as shown in Fig.1. Ottman and et. al. [7] and [8] pointed out that the power extracted from PEH is increased by 400% and 325% as compared to SPEH. Due to only the step-down characteristics of a buck converter other literatures introduced a buck-boost converter to extend the operating limits of the converter to work as step-down or step-up [9], [10]. A fly-back converter is used in some literatures to extend the operating range of the PEH [11].

The transition of the PEH terminal voltage between its peaks happened when the load is isolated (all rectifier diodes are in OFF state) as shown in Fig.2. This dissipates considerable amount of energy through the internal capacitor and resistor of the PEH which considerably reduces its extracted power and efficiency. Flipping the voltage through an external inductor at short time can extract most of this dissipated power to the load and increases the output power considerably. This technique is called Synchronized Switch Harvesting on Inductor (SSHI). This technique was first introduced by Ottman and et. al. [7]. This technique increased the output power by more than 900% compare to the same PEH without using the SSHI technique [7], [10]. Some researchers used inductor in parallel with the PEH [12]-[13] and others used the inductor in series [16], [17]. Depending on the results and comparison of many literatures [14], it is concluded that the parallel SSHI technique is better than the others. For this reason, the SSHI is used in this paper.

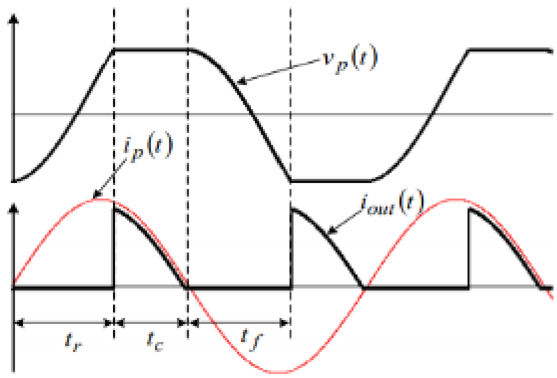

Fig. 2 PEH Voltage and Current with output current of PEH without SSHI

III. NEW PROPOSED CIRCUIT

The new proposed circuit performs an envelope detector for the PEH circuit effectively. In the NPC, C1 and C2 are used as negative and positive voltage peak detectors. The voltages and current of each element of the NPC are shown in Fig.3.

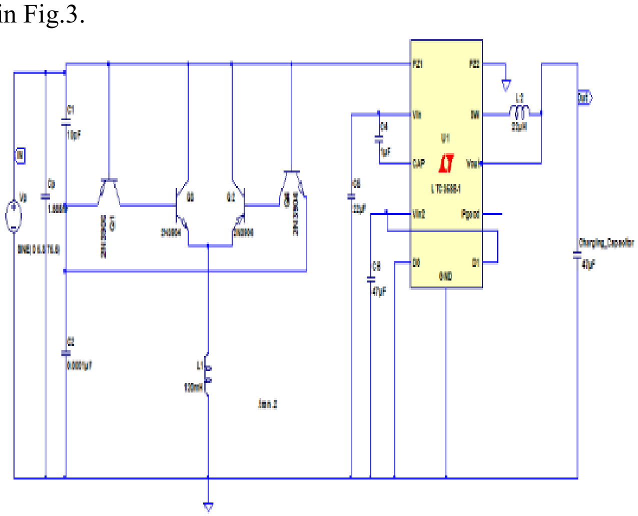

Fig. 3 New purposed circuit

This circuit is divided into three main parts: piezoelectric voltage generator, flipping circuit and voltage regulation circuit (LTC 3588-1). The positive peak detector having capacitor C1, C2, Transistors Q1, Q3 and inductor L1. And for negative peak detector, capacitor C1, C2, transistor Q2, Q4 and inductor L1 are involved as shown in the figure 3. Table 1 Shows bill of materials of proposed circuit.

IV. SIMULATION RESULT

As mention in an earlier session, the circuit is divided into three major parts, first part detects positive peak voltage, second detects negative peak voltage and third is harvester circuit.

TABLE I BILL OF MATERIALS

Component	Description
Capacitor (C1)	10pF, 25V
Capacitor (C2)	100pF, 10V
Charging Capacitor (C3)	47µF, 16V
Capacitor (C4)	1µF, 6V
Capacitor (C5)	22µF, 16V
Capacitor (C6)	47µF, 6.3V
Capacitor (Cp)	0.0001nF, 25V
Inductor (L1)	120mH, 69mA
Inductor (L2)	22µH, 1.4A
Transistor (Q1)	PNP, 2N3906
Transistor (Q2)	PNP, 2N3906
Transistor (Q3)	NPN, 2N3904
Transistor (Q4)	NPN, 2N3904
IC (U1)	LTC3588-1

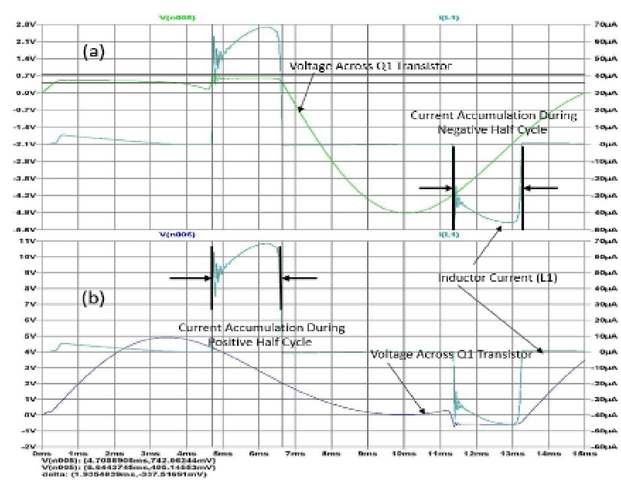

Fig. 4 Inductor current Accumulation during positive and negative half cycle

When the input voltage was reached at peak point then the inductor (L1) used to store the energy in form of electromagnetic. Due to this, the delay also occurred in the circuit and it was around 1.9354ms as shown in Figure 4. It also observed that the value of inductor (L1) current was at 68.383425µA in the positive half cycle and at -45.75289µA in the negative half cycle. This current difference was produced due to using nonideal components like transistors and capacitors.

The inductor L1 has the main role in this operation. When the voltage across C1 and C2 is less then peak voltage than inductor bypass the circuit current to ground and flip operation performed. The voltage and current across inductor shown in the figure below and the regulated output voltage is also shown in the figure 5. LTC 3588-1 have full wave rectifier and DC to DC regulation circuit. It generates the regulated output voltage around 3.3V and delay of regulation is around 17.472ms as shown in figure 6. It is also observed that the system loose the first and half cycles of input voltage Vp due to peak detectors.

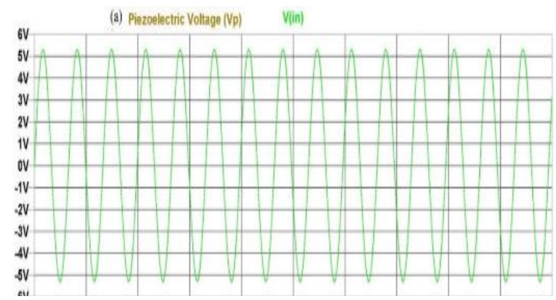

Fig. 5 Piezoelectric Voltage Vp

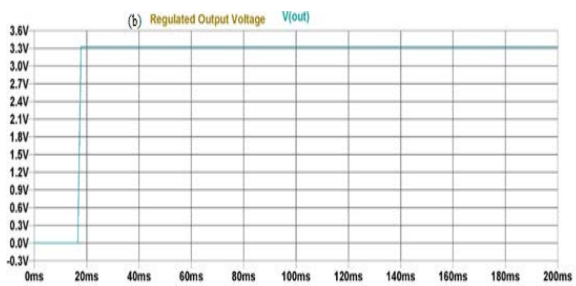

Fig. 6 Regulated Output Voltage V(out)

V. CONCLUSIONS

Using of self-power SSHI harvests more power from the PEH than battery driven SSHI technique. A new proposed SSHI circuit is introduced in this paper to increase the energy captured from PEH and extends its vibration frequency operating range. The NPC showed simple, effective, and higher efficiency and wider vibration frequency operating range compared others. Also, circuit reduced the weight, cost, and increased the reliability due to the reduction in the number of components. The regulated output voltage is around 3.3V with 17.472ms delay.

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